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ERB-970

A System for Static and Dynamic Performance Testing of Terrestrial Photovoltaic Power Conditioners

J. Ayer

April 1985

Canada

NRCC No. 24749

86-02692/

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A SYSTEM FOR STATIC AND DYNAMIC PERFORMANCE TESTING OF TERRESTRIAL PHOTOVOLTAIC POWER CONDITIONERS

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ABSTRACT

In the relative new technology of photovoltaic power conditioners, there is a need for engineers to identify and evaluate the various potential problems during the research and development stages of a power conditioner. Essentially these problems are related to safety, load/no-load performances, reliability and EMI/RFI generation.

The subject of this report is a test system capable of providing a simulated solar array input power to the power conditioner (inverter) under test together with instrumentation for measuring the various input/output parameters of the device tested under different operating conditions statically or dynamically.

The system is capable of testing either a stand-alone or an utility-interactive power conditioner, single phase 240 V, 60 Hz with an input power up to 11 kW. Most of the system parameters are manually metered and also automatically measured by means of transducers whose outputs are processed and printed by a data acquisition system.

RÉSUMÉ

La technologie relativement récente des conditionneurs de puissance photovoltaïques soulève le problème de l'identification et de l'évaluation par les ingénieurs des divers problèmes potentiels pendant les étapes de recherche et développement d'un conditionneur de puissance. Essentiellement, ces problèmes sont liés aux performances avec et sans charge, à la fiabilité, ainsi qu'à la production de brouillage électromagnétique (EMI) ou de brouillage radioélectrique (RFI).

Le présent rapport décrit un système de mesures qui permet de simuler la puissance produite par un générateur solaire et appliquée au convertisseur de puissance (onduleur) qui fait l'objet de la vérification; le système comporte l'instrumentation nécessaire à la mesure des divers paramètres d'entrée/sortie du dispositif à l'essai, dans diverses conditions d'exploitation statiques ou dynamiques.

Le système peut servir aux essais d'un convertisseur autonome ou interactif avec le réseau de distribution, et dont les caractéristiques sont les suivantes: tension monophasée de 240 V, 60 Hz, puissance d'entrée jusqu'à 11 kW. La plupart des paramètres du système peuvent être mesurés manuellement ainsi qu'automatiquement au moyen de transducteurs dont les sorties sont traitées et imprimées par des systèmes de saisie des données.

A SYSTEM FOR STATIC AND DYNAMIC PERFORMANCE TESTING OF TERRESTRIAL PHOTOVOLTAIC POWER CONDITIONERS

J. Ayer

INTRODUCTION

A test system that can simulate as closely as possible the normal operating conditions of a device (or system) under test provides the best test simulation to validate the devices' performance parameters for reasons of analysis, improvement, or modification.

The test system described consists of a simulated photovoltaic array power generator with the characteristics of a PV array, which together with instrumentation that provides a test realism which can measure the input and output parameters, i.e., volts, amperes, phase angle, watts, vars, and frequency under different modes of device test configuration (1). These parameters are manually measured and also automatically measured by transducers whose outputs are processed and printed by a data acquisition system.

Repeatable and continuous tests can hence be performed and devices' operational reliability (burn-in) characteristics under load can be analysed. After the device (or the system) is tested in the laboratory, it can then be tested under real life normal operating conditions. The results can then be compared for modifications.

The test system is configured to support the design and development of photovoltaic stand-alone or utility-interactive power conditioners up to an input power level of about 11 kW. Detailed specifications are given elsewhere in this report.

The test system is designed to be compatible with the requirements of the "CSA Draft Standard Specification F-381, Photovoltaic Power Conditioning Subsystems" (2), final (5th) draft and the "IEEE Standards, Project P-939, Guide for Terrestrial Photovoltaic Power Conditioner Subsystem Testing (Utility-Interactive, Single Phase)" (3). These documents in their final form may be used by industry as standards.

THE RATIONALE

The implementation of such a test system is that during the development stages of a device, the device's potential engineering, institutional, and

design problems must be identified. This is essential when a new technology is involved, to prevent major problems in the areas of safety, performance, reliability, and costs. The test for reliability is indicated by the ability of the test system to locate component level failures directly or indirectly in the device under test by means of the instrumentation and test modes. By synergistically selecting the test modes, a number of tests can be eliminated without affecting the overall confidence level of system performance (4). The ON-OFF power cycling (5) during the load tests provides sufficient electrical and thermal stresses to weed out the infant failures of most components in the device under test and can provide adequate information on component derating, failure types, and rates for system reliability/maintainability calculations.

METHOD AND SCOPE

The test system as shown in Fig. 1 consists of a solar array simulator with a three-phase 208 V input set to provide an output of ~160 to 240 V dc and up to ~45 A. It reproduces the array dynamic characteristics while operating under a variety of loads with different resistance and time constant values. The output of the simulator is connected to the inverter under test. The three-phase input power to the simulator, the dc voltage and current injected into the inverter (or power conditioning unit) under test are monitored manually; the latter two measurements are also fed into the data logger by means of transducers.

The ac power output of the inverter is connected to the 60 Hz power grid intertie in the case of an utility-interactive power conditioning systems through two directional kilowatt-hour meters connected in such a manner as to indicate the energy supplied to and/or obtained from the grid.

Manual metering of inverter output rms voltage, rms current, line frequency, output power, power factor, and reactive power are indicated by a power analyser instrument and meters. By means of transducers these characteristics are also measured for inputs to the data-logger for further processing.

During the utility-interactive tests the harmonics in the line can be measured, averaged, and printed by the data logger. Alternately this operation can also be performed without the device under test, i.e., measuring the existing line harmonics. The comparison between the two tests can then provide some indication of the distortion levels caused by the device under test. During the testing of inverters over a period of hours any power disturbance, i.e., sag, spike, transient, or discontinuity can be measured and recorded by means of a Power Disturbance Analyser and Recorder.

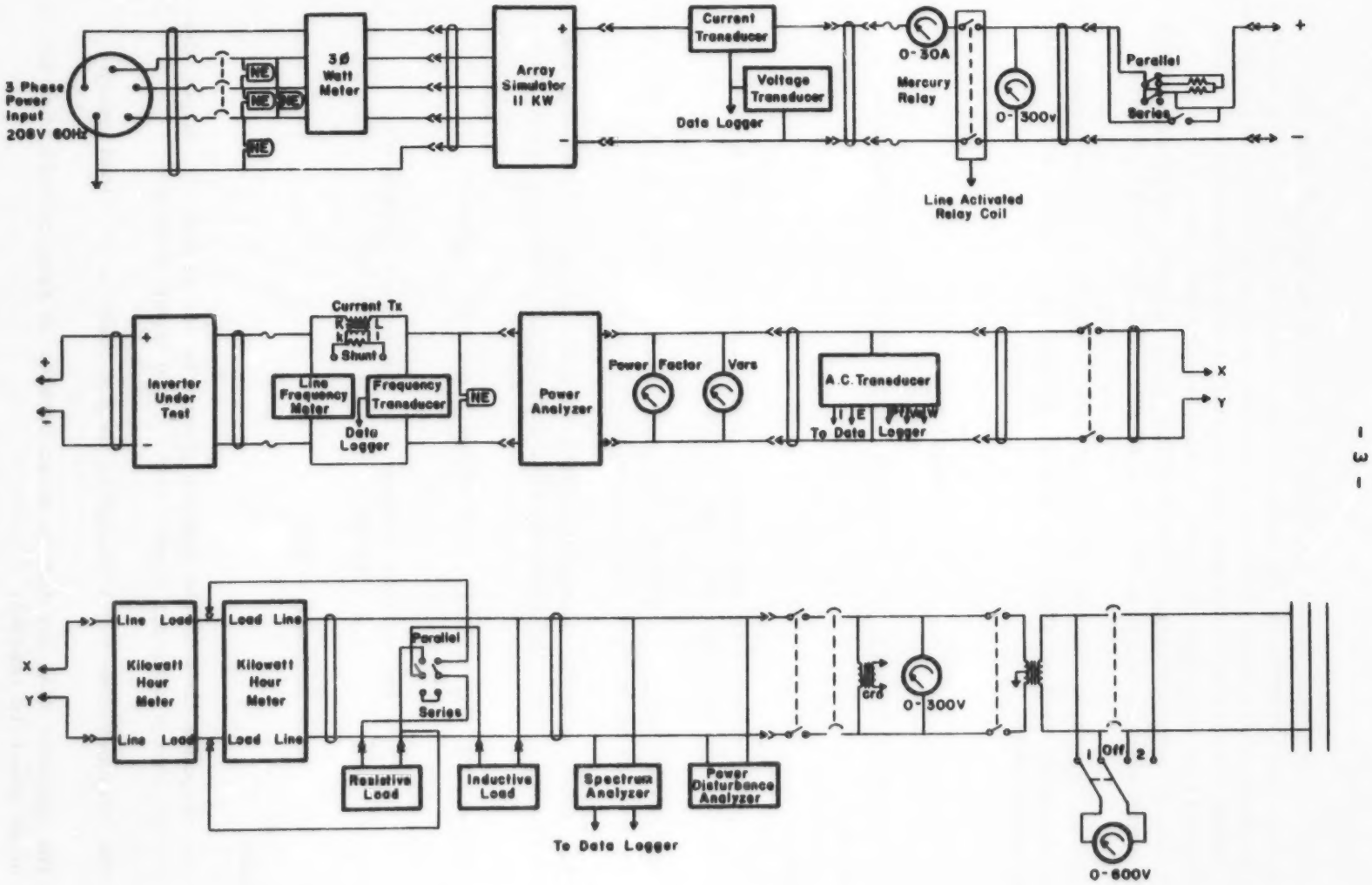


Figure 1. Complete test system

In general, the test system is capable of following most of the test procedure requirements of the commercially available photovoltaic power conditioners at present. Redundant protection is provided by means of fuses and circuit breakers throughout the system. A safety protection against the possibility of supplying dc power to the device under test which may energise an open circuited section of the grid is provided by means of a high speed mercury relay on the dc side but activated by the ac grid.

Local resistive and inductive loads are provided to be connected to the inverter under test to study the phase and frequency shifts under sudden load conditions.

CAPABILITY

Although other tests are possible, only the essential ones are described.

Static

1. The power consumed by the inverter under test just prior to supplying the load or storing, i.e., the no load power loss.

2. The output voltage, current, and power factor at full, half, and quarter rated load with fixed input dc volts and current.

3. The total harmonic distortion (THD) in the current waveform and the distortion level for each harmonic current at different rated loads,

where $$THD = \frac{1}{I_{fo}} \left[\sum_{n=2}^{\infty} (\text{nth harmonic current component})^2 \right]^{1/2}$$

I_{fo} = RMS current component at fundamental frequency, i.e., 60 Hz.

n = harmonic number

Dynamic

1. The response time of the maximum power tracker circuit to output the abrupt change in input power, i.e., cloud cover condition.

2. The response time for a change in output power with a load change.

3. The response time for the dc or ac breaker to open circuit when the dc or ac power is removed.

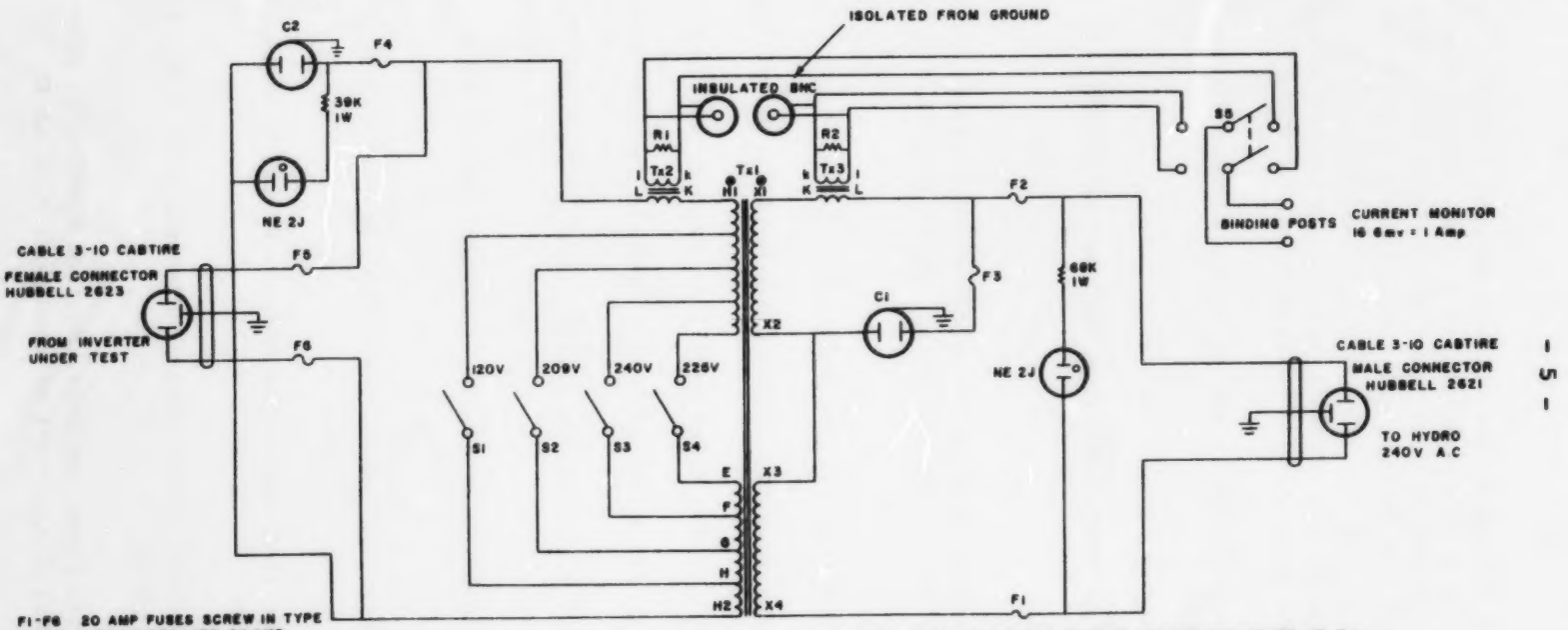


Figure 2. Power line "dip" simulator

4. The "out-of-sync" voltage. The utility voltage tolerance is normally between 208 and 255 V on a nominal 240 V line. These voltage variations, if sudden can cause some inverters to trip their power breakers. In order to detect and measure this trip voltage a test system was devised as shown in Fig. 2. The tapped transformer is connected between the output of the inverter and the grid intertie. The taps can be changed on load simulating a voltage "sag" or "surge".

5. The phase and frequency shift due to sudden changes in load impedance values.

LIST OF INSTRUMENTATION USED IN THE SYSTEM

Meters and Instruments

The instruments marked with an * are described in detail under "Major Equipment Specification". Other equipment specifications are available on request.

1. Three-phase 240 V wattmeter, Yew Model 2105-445

*2. 11 kW solar array simulator, Abacus Controls Inc., Model SAS1

3. DC voltmeter 0-300 V, Yew Model 2101-25 - nominal accuracy ±1% full scale

4. DC ammeter 0-30 A, Yew Model 2101-19 - nominal accuracy ±1% full scale

5. AC voltmeter 0-300 V, Yew Model 2102-6 - nominal accuracy ±1% full scale

6. Frequency meter 40-99.99 Hz, Power Instruments Model 2002 - nominal accuracy ±0.01%

7. Var meter 0-10 kvar (LAG-LEAD), Yew Model 2107-225 - nominal accuracy ±1% full scale

8. Power factor meter (LAG-LEAD), Yew Model 2107-225 - nominal accuracy ±4% in phase angle

9. Single phase Watt-hour meter, General Electric (Can.) Model I 70S - nominal accuracy ±0.5%

*10. Multi-range digital power analyser, Magtrol Model 4612 PF - nominal accuracy (Ref. ANSI C39.6) ±25% of reading + 0.2% of FS

*11. Spectrum analyser, HP Model 3582A

*12. Power disturbance analyser, Power Sciences Model PDA-22060

Transducers

1. DC current photo isolated transducer, NRC Model PF-19-27B - nominal accuracy ±1.0%

2. Frequency transducer, Scientific Columbus Model 6284B - nominal accuracy ±0.02% of center frequency

3. DC voltage transducer, Ohio Semitronics Model VT7-8B - nominal accuracy ±0.5% rated output

4. Power factor, watt, and VA transducer, Ohio Semitronics Model PC-9-50 - nominal accuracy ±0.75% rated output

5. True RMS voltage transducer, Ohio Semitronics Model VT-240 - nominal accuracy ±0.5% rated output

6. True RMS current transducer, Ohio Semitronics Model CTIR - nominal accuracy ±0.5% rated output.

Load Banks

*1. Avtron Model K595, resistive variable steps, 55.5 kW at 240 V - 3ph 60 Hz

*2. Avtron Model K596, inductive variable steps, 41.6 kvar at 240 V - 3ph 60 Hz

Data Acquisition

Analog Devices, Macsym 2 Model, 16 bits 32 K words, stand-alone type.

CONCLUDING REMARKS

The system is capable of performing many more tests than those presented here. In order to compare it with a much more accurate and sophisticated system such as the one in ref. 3, at Sandia Laboratories, New Mexico, it requires further "fine tuning" and comparison tests on identical power conditioning devices. However, due to recent government cutbacks, this has not been possible. Nonetheless, the system as it stands at present can provide a considerable support in the development of PV power conditioners for the private and public sectors.

MAJOR EQUIPMENT SPECIFICATIONS

11 kW Solar Array Simulator. Abacus Controls Inc., Model SASI

(After Specifications description, Abacus Controls Inc., Somerville, NJ.)

Input

1.1 120/208VAC ±10%, 55-65Hz, three phase

Output

2.1 Voltage adjustable 0-300VDC

2.2 Current adjustable 0-55ADC

2.3 Maximum power limited to 11KW

2.4 Adjustable Parameters

a. Open circuit voltage

b. Short circuit current

c. I-V characteristic current slope

d. I-V characteristic voltage slope

e. Operating position on I-V curve

Dynamic Response

3.1 Switching regulator: 50Hz minimum

3.2 Series regulator : 120Hz minimum

Physical

4.1 Cabinet on casters

4.2 Height: 60 inches, Width: 23 inches, Depth: 30 inches

4.3 Weight: 400 lbs.

Multirange Digital Power Analyser. Magtrol Model 4612 PF

(After Specifications description, Magtrol Inc., Buffalo, NY.)

GENERAL INFORMATION

WAVE SHAPE Since no current or potential transformers are utilized the unit will define such highly distorted wave shapes as SCR power control, half-wave rectified sources, etc. Although the unit is intended primarily for AC applications, DC power measurement can be made at slight reduction in accuracy, generally less than .2 percent of full scale.

POLARITY With DC, no polarity of the input is required or indicated. With standard line voltage on which a common or ground side exists, common-mode capacity effects are reduced by observing black-to-black and white-to-white relationship between the color-coded input connections and the standard power line.

GROUNDING Cabinets and all digital and analog outputs are, and must be, maintained common to ground.

READOUTS Two 4-digit (amps and volts) and one 5-digit (watts) or 4-digit (power factor) flat-plane gas-discharge displays, each .6" high. Displays are continuous (nonblinking). Format is floating point for maximum resolution.

A floating-point display means that as a displayed value is decreased, aggravated by such factors as low power factor, high crest factor, etc., the decimal point automatically moves from right to left to provide the best possible indication.

BURDEN The potential measuring burden is included in the current and power measurements. On both the 15- and 30-volt ranges, at full scale, it is .14 milliamperes; and on the 150-, 300-, and 600-volt ranges it is .6 milliamperes. Selecting the worst case ranges this represents a maximum error of .03 percent full scale on the 2.0-amp range and .36 volt-amps on the 600-volt (at full scale) wattmeter range.

The current burden does not affect the measurement accuracy, and is evident only as a voltage drop across the unit. The maximum voltage drop is approximately .25 volts at full scale, and occurs on the 20-amp range.

INSTRUMENTATION POWER The unit operates on standard 115V 60Hz, or optional 230V 50Hz, 3-wire single phase.

FULL-SCALE RANGES

INDICATED WATTS AT FULL SCALE (are as shown at volts/amps intersect)					
AMPS → / VOLTS ↓	2.000	5.000	10.00	20.00	50.00
15.00	30.000	75.000	150.00	300.00	750.00
30.00	60.000	150.00	300.00	600.00	1500.0
150.0	300.00	750.00	1500.0	3000.0	7500.0
300.0	600.00	1500.0	3000.0	6000.0	15000.
600.0	1200.0	3000.0	6000.0	12000.	30000.

DISPLAY HOLD AND PF MEASUREMENTS

Two latching illuminated pushbutton switches are available to the operator for the following functions:

DISPLAY HOLD When this button is depressed, the displays are latched indefinitely.

WATTS/POWER FACTOR When this button is depressed the watts reading is dropped and the internal processor performs the following arithmetical function:

$$PF = \frac{\text{watts}}{\text{volts x amps}}$$

Since this is a digital function, the accuracy of the computation is absolute. However, the accuracy of the reading is dependent upon the individual accuracies of each parameter.

The digital reading, although five digits, is effectively four because the power factor as displayed by this instrument is always less than one: i.e., 0.9999 maximum.

ACCURACY (REF ANSI C39.6)

Rated accuracy (±.25% of reading +.2% of F.S.) from 50 to 100 Hz single phase, 15 to 30°C, crest factor <2:1, power factor 0 to 1.0 lead or lag.

Rated accuracy DC and 400 Hz as stated above + (±5 least significant digits).

The above accuracies apply to amps, volts, and watts individually.

Power Factor typically better than (±.75% reading) ±3 LSD.

NOTE: The power factor accuracy is based upon a probability factor. The theoretical limit could be the sum of the combined errors for each parameter.

Spectrum Analyzer. HP Model 3582A

(Specifications reprinted from "Operating Manual, Model 3582A Spectrum Analyzer". ©Copyright 1978 Hewlett-Packard Company. Reproduced with permission.)

FREQUENCY MODES:

0-25 kHz Span: The selected measurement is performed over the fixed frequency range of 0 Hz to 25 kHz independent of the FREQUENCY SPAN control.

0-Start: The selected measurement is performed over the frequency range defined by the FREQUENCY SPAN control and with a fixed start frequency of 0 Hz.

Set Center: The selected measurement is performed over a frequency range with a width determined by the FREQUENCY SPAN control and with a center frequency variable with 1 Hz resolution.

Set Start Or Set Center Mode: 5 Hz span to 25 kHz span in a 1-2.5-5-10 sequence.

FREQUENCY ACCURACY: The frequency accuracy is ± 0.003% of the display center frequency.

FREQUENCY RESOLUTION: The marker resolution is equal to the calculated point spacing for the selected frequency span and number of channels.

Set Start: The selected measurement is performed over a frequency range with a width determined by the FREQUENCY SPAN control and with a start frequency variable with 1 Hz resolution.

FREQUENCY RANGE: 0.02 Hz to 25.5 kHz. The low frequency limit is the result of the DC response.

FREQUENCY SPANS:

0 Start Mode: 1 Hz full scale to 25 kHz full scale in a 1-2.5-5-10 sequence.

FILTER PASSBAND SHAPE:

	Flat Top	Hanning	Uniform
3 dB Bandwidth (single channel)	(1.4 ± 0.1)% of span	(0.58 ± 0.05)% of span	(0.35 ± 0.02)% of span
Shape Factor [60 dB bandwidth / 3 dB bandwidth]	2.6 : 1	9.1 : 2	716 : 20

The FLAT TOP PASSBAND SHAPE provides optimum amplitude accuracy. The UNIFORM PASSBAND SHAPE is optimized for use with transients and for use with the PERIODIC NOISE SOURCE, and the HANNING PASSBAND SHAPE provides an amplitude/frequency resolution compromise and is used for general noise measurements.

Single-Channel Analysis Parameters:

Frequency Span	Time Record Length ($1/\Delta f$)	Calculated Point Spacing (Δf)	Equivalent Noise Bandwidth: Flat Top	Hanning	Uniform
1 Hz	250 sec	4 mHz	14.5 mHz	6.00 mHz	4 mHz
2.5 Hz	100 sec	10 mHz	36.3 mHz	15 mHz	10.0 mHz
5 Hz	50 sec	20 mHz	72.4 mHz	30 mHz	20 mHz
10 Hz	25 sec	40 mHz	145 mHz	60 mHz	40 mHz
25 Hz	10 sec	100 mHz	362 mHz	150 mHz	100 mHz
50 Hz	5 sec	200 mHz	725 mHz	300 mHz	200 mHz
100 Hz	2.5 sec	400 mHz	1.45 Hz	600 mHz	400 mHz
250 Hz	1 sec	1 Hz	3.63 Hz	1.50 Hz	1.00 Hz
500 Hz	500 msec	2 Hz	7.24 Hz	3.00 Hz	2.00 Hz
1 kHz	250 msec	4 Hz	14.5 Hz	6.00 Hz	4.00 Hz
2.5 kHz	100 msec	10 Hz	36.3 Hz	15.0 Hz	10.0 Hz
5 kHz	50 msec	20 Hz	72.5 Hz	30.0 Hz	20.0 Hz
10 kHz	25 msec	40 Hz	145 Hz	60.0 Hz	40.0 Hz
25 kHz	10 msec	100 Hz	362 Hz	150 Hz	100 Hz

The corresponding dual-channel parameters are found by doubling the calculated point spacing and equivalent noise bandwidths and taking one half the time record length.

AMPLITUDE

AMPLITUDE MEASUREMENT MODES: 256 point amplitude spectra are measured in the single-channel mode. Two 128 point amplitude spectra are measured in the dual-channel mode.

AMPLITUDE DISPLAY MODES:

Log: 10 dB/major division
2 dB/major division

Linear: Constant voltage/major division

AMPLITUDE MEASUREMENT RANGE:

Log: The calibrated attenuator range is + 30 dBV to -50 dBV single tone RMS maximum input level in 10 dB ± 0.2 dB steps. The continuous vernier provides >10 dB of additional uncalibrated sensitivity between the 10 dB steps.

Linear: The calibrated attenuator range is +30 volts RMS to 3 millivolts single tone RMS maximum input in a 1-3-10 sequence. The vernier provides continuous coverage between the major steps. The AMPLITUDE

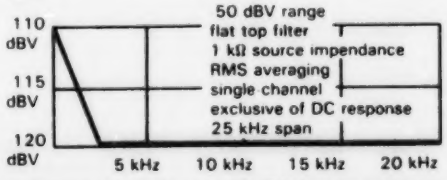
REFERENCE LEVEL provides 8 additional ranges down to 8 microvolts full scale.

DYAMIC RANGE:

Distortion Products: >70 dB below the maximum input level.

Spurious Responses: >70 dB below the maximum input level.

Noise:



DC Response: Adjustable to >40 dB below the maximum input level with the front panel DC balance adjustment.

AMPLITUDE ACCURACY:

	Log
Accuracy At The Passband Center: (Full Scale)	± 0.5 dB
Flat Top Filter:	+ 0. 0 1 dB
Hanning Filter:	+ 0. 1 5 dB
Uniform Filter:	+ 0. 4 0 dB

Overall accuracy is the sum of the accuracy at the pass-band center and the filter accuracy.

AMPLITUDE RESOLUTION:

Log: 0.1 dB with the marker

Linear: 3 digits with the marker

AMPLITUDE LINEARITY:

± 0.2 dB ± 0.02% of full scale

AMPLITUDE CALIBRATOR: The internal calibration signal is a line spectrum with nominal 1 kHz frequency spacing and a fundamental level of 22 ± 0 2 dBV on the log scales and 20 ± 0 5 volts on the linear scale.

AMPLITUDE OVERLOAD LIMITS:

Log: Overload occurs at 100% of the maximum input level which is equal to full scale when the AMPLITUDE REFERENCE LEVEL is set to NORMAL. When overload occurs spurious products may be displayed.

Linear: Overload occurs at 100% of the maximum input level which, depending on the input attenuator setting, is at 6/8 or 5/8 of full scale when the AMPLITUDE REFERENCE LEVEL is set to NORMAL. When overload occurs spurious products may be displayed.

PHASE

PHASE MEASUREMENT MODES: 256 point phase spectra are measured in the single channel mode. Two 128 point phase spectra are measured in the dual channel mode.

PHASE DISPLAY RANGE: From 200 degrees to -200 degrees.

PHASE ACCURACY: ± 10 degrees

PHASE RESOLUTION:

Display: 50 degrees/major division

Marker: 1 degree

TRANSFER FUNCTION

TRANSFER FUNCTION MEASUREMENT MODES: Dual-channel 128-point transfer functions are measured.

TRANSFER FUNCTION DISPLAY MODES:

Log Amplitude: 10 dB/major division
2 dB/major division

Linear Amplitude: Constant floating point fraction/major division

Phase: Constant 50 degrees/major division

TRANSFER FUNCTION MEASUREMENT RANGE:

Log Amplitude: Calibrated ranges of + 160 dB full scale to -80 dB full scale in 10 dB steps. The uncalibrated verniers provide continuous coverage between the 10 dB steps.

Linear Amplitude: Calibrated ranges of 4.0×10^{8} full scale to 4.0×10^{-8} full scale in factor of 10 steps. The uncalibrated verniers provide continuous coverage between the factor of 10 steps.

Phase Display Range: + 200 degrees to -200 degrees.

TRANSFER FUNCTION ACCURACY (STANDARD):
Amplitude: ± 0.8 dB
Phase: ± 5 degrees

TRANSFER FUNCTION ACCURACY (OPTION 001):

	.02Hz	5kHz	25.5kHz
Amplitude:	.4dB	± .8dB	
Phase:	± 2°	± 5°	

TRANSFER FUNCTION RESOLUTION:
Log Amplitude: 0 1 dB with the marker

Linear Amplitude: 3 digit scientific notation with the marker

Phase: 1 degree with the marker

COHERENCE FUNCTION

COHERENCE FUNCTION MEASUREMENT MODE: Dual-channel 128 point coherence functions are measured with RMS averaging only.

COHERENCE MEASUREMENT RANGE: The bottom display line is 0.0 and the top display line is 1.0.

COHERENCE FUNCTION RESOLUTION:

Display: 0.125 major division

Marker: 0.01

TRIGGER

TRIGGER MODES:

Free Run: A new measurement is initiated by the completion of the previous measurement.

External: A rear panel switch allows new measurements to be initiated by an external TTL pulse.

Input Signal: A new measurement is initiated when the input signal meets the specified trigger condition.

TRIGGER CONDITIONS:

Signal Conditions: Triggering can be selected to occur on a positive or negative going transition through the trigger level. The trigger level is adjusted between the time record overload limits by a continuous vernier.

Single/Multiple Triggers: Single shot triggering is specified by taking the instrument out of the REPETITIVE mode. The ARM control sensitizes the instrument to take another measurement in the non-repetitive mode.

INPUT CHANNELS

INPUT IMPEDANCE: $10^6\Omega \pm 5\%$ shunted by < 60 pf from input high to low for less than 75% relative humidity.

DC ISOLATION: Input low may be connected to chassis ground or floated up to 30 volts to reduce the effects of ground loops on the measurement.

INPUT COUPLING: The input circuit may be AC or DC coupled. The low frequency 3 dB roll off of the AC coupling is < 1 Hz.

COMMON MODE REJECTION:

50 Hz: > 60 dB

60 Hz: > 58 dB

INPUT CHANNEL CROSSTALK: < -140 dB between channels with 1 kΩ source impedance driving one channel and the other channel terminated in 1 kΩ.

OUTPUT SIGNALS

X Y RECORDER:

Vertical: 0 to 5.25V ± 5%

Horizontal: 0 to 5.25V ± 5%

Impedance: 1kΩ

Pen Lift: Contact closure during sweep.

NOISE SOURCE:

Periodic: Pseudorandom noise signal with spectral line spacings that match the calculated point spacing for the selected frequency span. The noise spectrum is band limited and band translated to match the selected measurement.

Random: Random noise signal; the noise spectrum is band limited and band translated to match the selected measurement.

Level: Vernier control from < 10 mV to > 500 mV RMS into a load of ≥ 50Ω when measured with a broadband True RMS voltmeter.

Periodic Noise Frequency Response: ± 1 dB with UNIFORM PASSBAND SHAPE and -10 dBV level.

Impedance: < 2Ω

IMPULSE SOURCE: A TTL low to high pulse with a period equal to the time record length.

DISPLAY

CRT:

Screen Size: 11.9 cm (4.7 in.) wide by 9.6 cm (3.8 in.) high.

Graticule: 10 major division horizontal by 8 major divisions vertical with internal illumination for CRT photography.

Text: Maximum of four 32 character lines of alphanumeric text.

ALPHANUMERIC ANNOTATION: Single or dual-channel configuration, input or stored trace, frequency calibration, amplitude calibration, equivalent noise bandwidth, relative or absolute marker frequency, relative or absolute marker phase, relative or absolute marker coherence, RMS noise density at the marker, time record collection time.

DISPLAY ACCURACY: Display accuracy is 3% of total height or width for 25 ± 15°C. Note that if numeric readings are taken visually from the displayed trace, this factor must be added to the basic accuracy specification.

TRACE STORAGE: A maximum of two independent traces may be digitally stored and recalled. Annotation information is not stored with the traces.

AVERAGE

AVERAGING MODES:

RMS: For each calculated frequency point the displayed amplitude is

$$\sqrt{\frac{1}{N}\sum_{i}^{N} A_i^2(f)} \quad \text{and the phase is} \quad \frac{1}{N}\sum_{i}^{N} \theta(f)$$

Peak: For each calculated frequency point the displayed amplitude is MAX Ai(f) and the phase is the corresponding value for the retained amplitude point.

Time: For each time record point the amplitude is

$$\frac{1}{N}\sum_{i} A_i(t)$$

The averaged time record is transformed to give the corresponding amplitude and phase.

NUMBER OF AVERAGES: 4 to 256 in a binary sequence plus exponential. Exponential in the RMS mode gives a running average with new spectral data weighted 1/4 and the previous result by 3/4. Exponential in the peak mode gives a continuous peak hold operation.

REMOTE OPERATION

PROGRAMMING: All analyzer front panel controls except the CRT controls, NOISE SOURCE LEVEL and TYPE, TRIGGER LEVEL, AMPLITUDE VERNIERS, and GROUND ISOLATION are remotely programmable via the HP IB.

DATA INPUT: Time records, amplitude and phase spectra, coherence functions, transfer functions and alphanumeric text can be input to the analyzer via the HP IB.

DATA OUTPUT: Time records, amplitude and phase spectra, coherence functions, transfer functions, alphanumeric text, marker values and control settings can be output via the HP IB.

GENERAL

ENVIRONMENTAL:

Operating Temperature: 0°C to + 55°C

Non-operating Temperature: -40°C to + 75°C

Humidity: To 95% relative humidity at 40°C

Operating Altitude: 4600 Meters (15,000 feet)

Non-operating Altitude: 6300 Meters (25,000 feet)

Shock: 30 G, 11 msec half sine wave on each of six sides.

Vibration: 10 Hz to 55 Hz at 0.010 inch peak to peak excursion.

OPERATING POWER: Switch selection of 110V + 5, 10% or 230V + 5, 10%, 48-66 Hz, less than 150 VA.

PHYSICAL PARAMETERS:

Size: 425.5 mm (16.75 inches) wide
552.5 mm (21.75 inches) deep
188 mm (7.4 inches) high

Net Weight: 24.5 kg (54 lbs.)

Shipping Weight: 29 kg (63 lbs.)

Power Disturbance Analyser Power Sciences Model PDA-22060

(Specifications reprinted from "Power Disturbance Technology," 2nd edition, by E. Cooper. Copyright Power-Matic, Inc. and Power-Science, Inc. 1981/82.)

Input Voltage (RMS)
Nominal 110V & 220V Models, see tabulated order information.

Continuous Operation (RMS)
Dynamic Input Range (2 Cycles)
Recording Range (RMS)
} See tabulated order information below.

Accuracy (RMS)
0.5% of F.S. from 30% to 65% of F.S. (1 Digit from 60V to 130V for 110V Models, 2 Digits from 120V to 260V for 220V Models).

Resolution (RMS)
0.5% of F.S. (1 Digit for 110V Models, 2 Digits for 220V Models).

Time Base (RMS)
Front panel switch selects ½, 1, or 2 Cycle Time Base. Note: Changing the Time Base causes an automatic reset of the RMS memories.

Display (RMS)
Three-Digit Numeric Readout, solid state.

Display Switch (RMS)
Three-position switch connects readout to three memories: Maximum High Line — Minimum Low Line — Instantaneous on-line voltage

Max. memory (RMS)
This memory is updated after each measurement (Time Base) to hold the highest RMS reading in storage until cleared by either the automatic recording circuit, or by the operator (Pushbutton).

Min. Memory (RMS)
This memory is updated after each measurement (Time Base) to hold the lowest RMS reading in storage until cleared by either the automatic recording circuit, or by the operator (Pushbutton).

On-Line Monitor (RMS)
A memory holds the last measurement for display while the next measurement is in process.

Carry-Through (RMS)
The power supply will carry operation through a two-cycle drop-out.

Power Fail
An indicator lights up, and the readout is blanked after power has dropped below 60% of nominal for longer than two cycles of the line voltage. (min. two cycle carry-through.)

Reset (Max/Min Memories)
Pushbutton resets the RMS memories and restores normal display after a power fail condition.

Spike Selector
A slide switch at the rear panel selects either Normal Mode (N/M) or Common Mode (C/M) spike measurements. Normal Mode is measured from Line to Neutral, Common Mode from Neut. to Ground.

Spike Threshold
Spikes are measured in eight Peak Volt levels of 50V, 100V, 250V, 500V, 750V, 1kV, 1.5kV, 2kV. (Normal Mode spike measurements represent the amplitude of the superimposed spike, regardless of phase relationship of polarity with respect to the line voltage sinewave.

Spike Response Time
The spike memory registers with 25 nanosecond response time.

Spike Accuracy
20% of reading. The spike measurement circuit and display will operate accurately even if the line voltage drops to 50% of nominal. However, the accuracy of the spike recorder output is impaired if the line voltage drops to less than 75% of nominal during the actual recording time.

Low Frequency Cut-off
In order to discriminate against low frequency components, the spike measurement circuit has a low frequency cut-off pole at approximately 1kHz. The roll-off slope is 20dB/decade.

Spike Display
Eight LED's display the peak amplitude of spikes (see Spike Threshold, above).

Spike Memory
Eight bit shift register holds and displays always the largest spike which has occurred. The memory is cleared either automatically by the recording circuit, or manually by the operator (pushbutton). The memory will hold the data through a six cycle drop-out.

Spike Test/Clear
Pushbutton on front panel tests and clears the memory stage by stage, each time the button is pushed.

Mode Selector
Slide switch on front panel selects manual monitor operation or automatic recording mode.

Manually Operated Monitor
In the manual mode, all memories are continually updated to hold the worst cast measurements indefinitely, until the operator clears the memories by pushbutton commands. A switch on the front panel (next to the strip chart recorder) disconnects power from the recorder drive motor to conserve chart paper when no recording is desired.

Automatic Recording
In the automatic recording mode, the unit will multiplex all memories sequentially, record the data in POWER CODE, and each memory is automatically cleared at the same instant when the data has been transferred into a buffer memory for recording.

POWER CODE (Pat. pend.)
The data which is being recorded on the strip chart is coded by a modulation technique so that characteristic strokes can identify the specific parameter on the chart. MAX and MIN RMS measurements are coded as multiplexed, vertical strokes in one minute intervals. Spikes are coded as short, horizontal strokes. A power fail condition is coded as a long, vertical stroke (two minute recording time) at zero scale. This power fail stroke is recorded when power returns after the interruption. At the beginning of a recording (i.e. when power is being turned on, or when the Mode Selector is being switched to the automatic recording position) the unit always starts with a power fail stroke.

Recorder
The strip chart recorder used in all models is a Gulton Rustrak Model 288, 1mA, 100 ohm, 1"/hr.

Chart Paper
See tabulated order information below.

Operating Temperature
0 to 40°C

Dimensions
W - 5" (13cm), H - 11.5" (29cm), D - 12" (31cm)

Power Cord
6 ft (180cm), 110V plug is NEMA 5-15P, 220V plug is NEMA 6-15P. The instrument case is grounded via the third conductor in the power cord.

Storage Temperature
-20 to +60 C

Weight
20 lbs (9Kg) approx.

Load Bank 1. Avtron Model K595

(After Bulletin 212, Avtron Manufacturing, Inc., Cleveland, OH.)

Operating Modes

Three Phase 240V 60 Hz or any lower voltage
Load Steps at 240V 0.50. 1. 2. 4. 8. 16 and 24 KW for total of 55.5 KW.

Single Phase 120V 60 Hz or any lower voltage
Load Steps at 120V 0.38. 0.73. 1.5. 3. 6. 12 and 18 KW for total of 41.6 KW.

Application

This load bank was designed for the testing and conditioning of electric power sources with a maximum load of 55.5 KW. It is highly portable with quick connections and simplified controls to ensure ease of operation. Components are rugged and full-rated for reliability in adverse environments. Current and voltage meters, controls, integral cooling fan, load components and rubber casters (two locking, two free) provide a totally self contained system. This unit will verify operational status to the most stringent test specifications.

Control Power

120V, single phase, 60 Hz
Line cord supplied

Cooling

120V, single phase, 60 HZ

Meters

Voltmeter, 0-250V, 1% full scale accuracy
Ammeter, 0-170A, 1% full scale accuracy

Weight

195 lbs. approx.

Load Bank 2. Avtron Model K596

(After Bulletin 243, Avtron Manufacturing, Inc., Cleveland, OH.)

- Dual Voltage Operation, 240/480
- 50 or 60 Hertz
- Four Wire Wye Configuration
- Provides 0.8PF When Used With 55 KW Resistive Load Bank
- Non-Saturating Iron Core Reactors
- Single and Three Phase Voltages
- Optional Metering

The Avtron Model K596 Reactive Load Bank is a small portable unit intended as a companion to the K595 portable resistive load bank. The load capability of the K596 is sized to provide convenient 0.8 power factor loading to 60 hertz generators when used with a K595 load bank. The load steps in the K596 reactive load bank are arranged to compliment the load steps of the K595 and to provide 0.8 power factor at each step.

Since the resistive load bank rating is 55.5 KW at 240 volts, the K596 provides 41.6 KVAR at this operating point. For K595 resistive load banks with 480 volt capability, the K596 also provides 40.5 KVAR to compliment the 54 KW rating. At 240 volts, the three phase balanced load steps are 18, 12, 6, 3, 1.5, .75, and .375 KVAR. At 480 volts, the load steps are 18, 12, 6, 3, and 1.5 KVAR.

The Model K596 Reactive Load Bank may also be used for 50 hertz operation. In the 240 volt mode, it may be used up to 208 volts, 50 hertz, with a rating of 37.5 KVAR. At 380 volts, 50 hertz, the rating is 30.5 KVAR.

The K596 Portable Reactive Load Bank provides additional versatility in that it is configured in a four wire wye circuit, which enables it to be used in a single phase loading applications. When so connected, the K596 provides full load capability at 138 volts and 277 volts, 60 hertz.

Reactors:

The reactors are designed and manufactured by Avtron. They are of iron core construction, with a power factor of less than .05 at 60 hertz. At rated voltages and frequency, the applied load will be within ± 5% of selected value.

Optional Metering:

Metering is available as an option. The metering is installed in the control panel. All meters are analog with 4½ inch wide faces. A phase selector switch can also be provided.

- Frequency 45-65 Hz, 2% of span
- Voltmeter 1% of full scale accuracy
- Ammeter 1% of full scale accuracy
- Wattmeter 2% of full scale accuracy
  (one phase L-N switched with volts and amps)

Control Panel

The K596 Reactive Load Bank is equipped with a control panel mounted at a convenient height on the enclosure. From this operator's station, the operating voltage may be selected and control power turned on and off. Toggle switches are provided to energize each of the load steps. These load step control switches can be turned on in any combination to provide a reactive load from 0 to the full rating of the load bank. In addition, a master load switch is provided which allows simultaneous application of all loads selected by the load step switches. This allows for shock loading of generators.

Physical Description

The Model K596 Reactive Load Bank is packaged in a rugged metal enclosure, with screened sides to allow natural convection cooling of the load reactors. A solid top is provided to permit the top surface of the unit to be used as a work surface. Below the control panel, a hinged panel is provided to enable convenient power connections to the four terminals of the load bank. This panel is hinged horizontally, such that in the open position it covers the control panel to prevent load operation with this compartment opened. When lowered, this panel is held nearly closed by gravity, and quick coupling fasteners are used to secure this panel closed. These features, with an interlock switch requiring the fasteners to be closed for operation, help assure safe operation of the load bank.

The enclosure is mounted on four heavy duty casters, two fixed and two steerable, for portability. The steerable casters have wheel locks to prevent inadvertent movement of the load bank.

The weight of the K596 is approximately 650 pounds.

ACKNOWLEDGEMENTS

The work done by Pierre Gariépy and others in fabrication, testing, and commissioning of the system at various levels is greatly appreciated. This project was partly funded by the Division of Energy, NRC.

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